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7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
Northwestern University Evanston Campus
1801 Maple Avenue

Evanston, IL 60201 -3149

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14. ABSTRACT

15. SUBJECT TERMS

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RPPR Final Report
as of 03-May-2019

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INVESTIGATOR(S):

Name: Gregory Scott Kanter
Email: gregory.kanter@northwestern.edu
Phone Number: 8474671801
Principal: Y

Organization: **Northwestern University Evanston Campus**
Address: 1801 Maple Avenue, Evanston, IL 602013149
Country: USA
DUNS Number: 160079455
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Title: Superconducting Single Photon Counter for Quantum Information Processing and Communications
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Report Term: 0-Other
Submitted By: Gregory Kanter
Email: gregory.kanter@northwestern.edu
Phone: (847) 467-1801
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Major Goals: This DURIP project is to acquire a superconducting single photon counting system. The photon counting system will be used in future quantum optics experiments such as the measurement of entangled photons.

Accomplishments: We have acquired the superconducting photon counting system and set up all the parts required to operate it.

Training Opportunities: A graduate student, who during the course of this project has been admitted to PhD candidacy, has been trained on issues involving superconducting single photon detection.

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Gregory Kanter
Person Months Worked: 1.00
Funding Support:
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: bradley Elkus
Person Months Worked: 1.00
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International Collaboration:
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Kanter, Gregory S.

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Northwestern University
633 Clark Street
Evanston, IL 60208-0001

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14. ABSTRACT

Our group has worked extensively in the field of quantum communications over fiber optical cable. Many experiments in this field require single photon detectors (SPDs) with low noise (dark count) and high photon detection efficiency. This is especially true for multi-photon detection systems, as are typically used when measuring entangled photons. To improve the performance and aid the development of such quantum processing and communication systems, we propose to acquire a superconducting nanowire single photon detector (SPD) from Quantum Opus. The turn-key system has performance far exceeding other telecommunication band sensitive SPDs, including 80% detection efficiency at 1550 nm, <160 ps timing resolution, and <100 dark counts per second. A cryo-cooler capable of cooling up to eight detectors is included in the proposed system, leading to an upgradable and completely self-contained system. We plan to use these detectors in various experiments that generate and manipulate quantum states of light.

15. SUBJECT TERMS
single photon detection, quantum optics, quantum networks, nonlinear optics, fiber optics.

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Gregory Scott Kanter

19b. TELEPHONE NUMBER *(Include area code)*
847-467-1801

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Superconducting Single Photon Counter for Quantum Information Processing and Communications

Sponsor Award #: W911NF-17-1-0184

Contract Funds Obligated: $109,600

Date of performance: 4/15/2017 – 7/14/2018

PI/Author: Gregory Kanter

Equipment Acquired: Single photon detection system featuring a superconducting nanowire detector

Vendor: Quantum Opus

- QO-NPD-1550-HDE: High Detection Efficiency Nanowire Detectors (4); $80,000
- QO-CRYO-HC4E2: Cooled compressor for nanowire detectors and electronics; $55,000
- Collaboration Discount; ($20,000)
- Existing cryo-cooling system trade in; ($20,000)
- Shipping and insurance; $1,000

Total to Quantum Opus: $96,000

Notes: we re-negotiated this purchase to get discounts for collaboration and a trade in of our cryo-cooling system. This allowed us to extend the detection system to 4 channels (instead of 2 channels).

Vendor: Swabian instruments GmBH

- Time Tagger 20; time tagger for counting/tagging correlated photons; $10543.47
- Shipping charge; $104.38

Total to Swabian: $10,648.10

Notes: Time Tagger allows for measurement of the timing and correlations of signals from the Quantum Opus nanowire detectors. This purchase was enabled by this low cost time tagger just coming on the market in 2018. It greatly extends our ability to localize the timing of detection events.

This single photon detector (SPD) system has many uses in our quantum optics laboratory. It has taken a considerable amount of time to acquire and set-up the system, in part due to manufacturer delays and in part due to changes needed to the physical laboratory (such as managing water flow for the cooling system). We now have all the components set-up and are preparing to use them in a project called “Integrated Optics for Single-Photon Nonlinear Interactions.” The long range goal of this project is to build quantum photonic integrated circuits (PICs) using thin film Lithium Niobate (TFLN). In particular TFLN can have much smaller mode size than standard lithium niobate waveguides, thereby effectively increasing the nonlinear interaction by 1-2 orders of magnitude. This will allow much more effective interactions between single photons, making functions like heralded entangled pair generation much more practical.

TFLN can also realize very small electro-optic modulators and basic components like wavelength division multiplexers (WDMs), which can be combined to form simple quantum circuits. No other material medium we know of allows the range of nonlinear, electro-optic, and linear functions of TFLN. An example of a potential PIC implementation is shown in Fig. 1. This project is in collaboration with the Fathpour group at University of Central Florida, who are experts in TFLN fabrication.

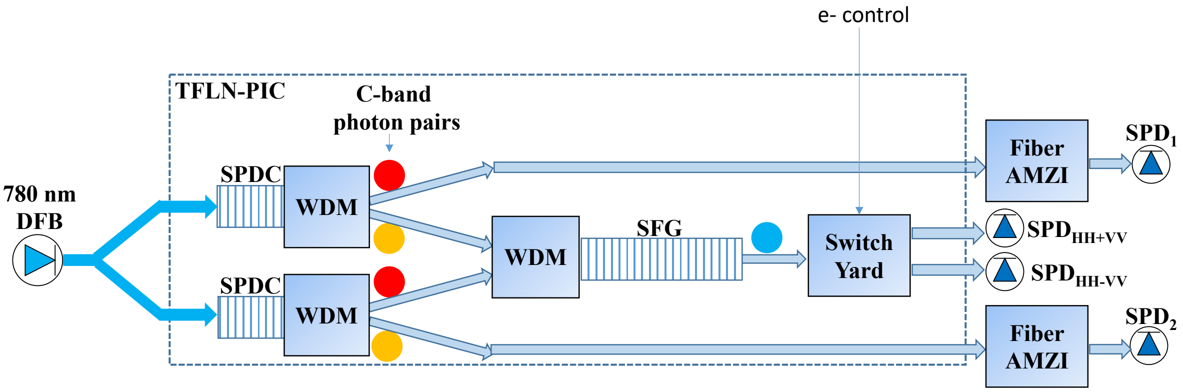

Fig. 1. *Conceptual diagram of photonic-integrated circuit implementation of entanglement swapping, making use of single-photon nonlinearity to enhance performance. The SFG photon detected at* SPD_{HH+VV} *or* SPD_{HH-VV} *heralds the entanglement expected in the accompanying (non-directly interacting) photons.*

We now have TFLN waveguides in our lab that have been tested at the fabrication facility to yield a small signal second harmonic generation (SHG) conversion efficiency of >2000%/W/cm^2, which is more than an order of magnitude more efficient than standard devices. We aim to use this device to generate quantum correlated photon pairs. We plan to conduct an experiment similar to Fig. 2, which will be the first demonstration we know of where cascaded nonlinearity is used to generate correlated photon pairs on the course wavelength division multiplexed (CWDM) grid. The experiment is enabled by the very short (sub-mm) waveguide that consequently has a large pair generation bandwidth to cover the CWDM bandwidth, which for instance can be pairs at 1470 and 1610 nm (140 nm separation).

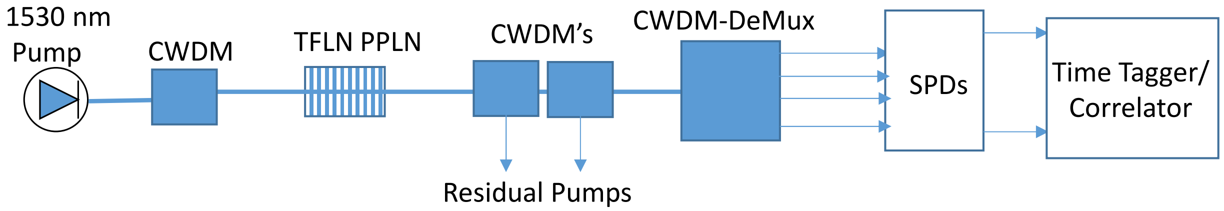

Fig. 3. *Conceptual diagram of CDWM grid pair generation enabled by the superconducting SPD system*

Another experiment that uses a programmable filter is shown in Fig. 3. This single-experiment that can be used to emulate any filtering system and predict performance with any given discrete components. It would open the entire C-band of operation for quantum signal generation by using two pumps just outside the C-band (e.g. 1510 and 1570 nm) to exploit a cascaded nonlinear interaction to generate signal/idler photon pairs continuously throughout the C-band.

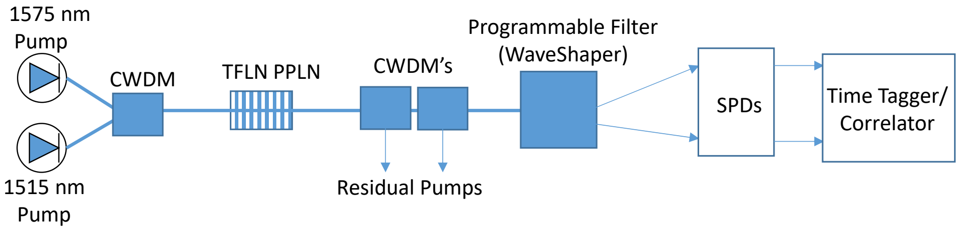

Fig. 3. *Conceptual diagram of full C-band pair generating using TFLN enabled by the superconducting SPD system. The programmable filter allows for complex measurements such as the joint correlation spectrum, while the short but still highly efficient TNLN PPLN gives access to the entire C-band.*

The main challenge of this experiment is the very small expected pair generation rate. The small rate stems from the small length of the waveguide (0.6 mm) making the pair generation probability small for reasonable pump powers, and the large loss of the programmable optical filter (>5 dB for both the signal and idler). Assuming the programmable filter has 3 dB more loss at the signal and idler than fixed filters, the use of the programmable filter will reduce the measured pair rate by another factor of 4. These difficulties combine to make the expected pair generation rates small.

Luckily the superconducting SPDs have much lower dark count rates and much higher detection efficiencies than our prior SPDs, which is precisely what is needed to perform this experiment. The smallest measurable pair rate is related to the ratio of η^2/DCP^2, where η is the single photon detection efficiency and DCP is the dark count probability (per pulse in a pulsed system). The superconducting SPDs have a 4× improved detection efficiency and more than 100× reduction in DCP leading to the ability to detect pair generation rates more than 5 orders of magnitude smaller than our prior detectors. Furthermore, future experiments can also make use of the four superconducting detectors we have available to perform functions such as multiplexed heralded single photon generation.